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AUTHOR	Rasmussen, Bonnie
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ABSTRACT

Developed as part of a National Workplace Literacy Program, this lesson focuses on terms and mathematical operations associated with Statistical Process Control (SPC) in the foundry industry. With appropriate assistance and preparatory work, workers testing between grades 4 and 9 on the Test of Adult Basic Education Locator should be able to use the lesson. The individualized lesson is intended to supplement small-group SPC activities. It teaches terms and mathematics used in quality control at Bodine-Robinson and Robinson Foundry. Reading material is followed by questions that ask about the instructional material. Some terms that are covered include key characteristic, specification, aim, and control limits. Mathematics areas include adding and subtracting SPC measurements, adding and subtracting decimals, figuring averages, and figuring ranges. A true-false quiz on the material is provided. (YLB)

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PRE-SPC MATH FOR FOUNDRY WORKERS

A Lesson Developed for Robinson Foundry and Bodine-Robinson as part of a National Workplace Literacy Program
March, 1993

INTRODUCTION

This lesson was developed during a National Workplace Literacy Project to augment small group teaching. The lesson teaches math and reading skills needed by workers in the metalcasting industry. Skills and understandings focused on include these: adding, subtracting and dividing decimal numbers; figuring averages and ranges; understanding percentages; reading chemistry symbols; using SPC terminology; using metalcasting terminology; and using information presented in table form.
The learning package is structured to be used by individual learners. They read, study charts, answer questions about the information, and check whether their answers are correct. Responses for both correct and incorrect answers reinforce learning. A pre- and post-test is included.

Bonnie Rasmussen
Curriculum Development Specialist
PO Box 1235
Alexander City, AL 35010
205 329 8481

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In this lesson on

Pre-SPC MATH

you will learn about the terms and math used in Quality Control at Bodine-Robinson and Robinson Foundry.

As you read through the lesson, you will be asked questions about what you are learning.

Finally, you will do a short quiz on the lesson.

SPC charts keep track of *key characteristics* in the manufacturing process. For instance, charts keep track of these things:

amount of zinc in the holding furnace when pouring Ford Manifolds
amount of moisture content in sand from suppliers
amount of silicon in a test button from CL 30a iron

A wrong amount of any *key characteristic* gives you a defect. For example, too much silicon in CL 30a makes brittle iron.

The right amount for each key characteristic is figured out by the lab.

Here are two *specifications* the lab has set for new sand in the Bodine-Robinson process.

B-R NEW SAND

key characteristic	**specification**
moisture content	.1% maximum
loss on ignition	.22% maximum

moisture content: amount of water in the sand
loss on ignition: amount of material in the sand mixture that is *not* sand (for instance, sticks that ignite, or burn up, during testing)

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The lab's *specification* often sets a maximum for a key characteristic. You can't have more than .1% of moisture in new sand, for instance.

B-R New Sand

key characteristic	**specification**
% moisture content	.1 maximum

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Other times, the *specification* will be an exact number, or *aim* point. You should try to get exactly 3.25% carbon in CL 30a iron. 3.25% is the *aim*.

R-F CL 30a iron

key characteristic	Specification Aim
% carbon (CL 25 iron)	3.49
% carbon (CL 20 iron)	3.90
% carbon (CL 30a iron)	3.25
% carbon (CL 35 iron)	3.15

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Since you can't hit the aim point exactly every time, *upper control limits (UCL)* and *lower control limits (LCL)* are also set by the lab. In other words, CL 30a iron is OK if you get between 3.20% and 3.30% of carbon. (You might notice that the aim point, 3.25%, is right in the middle of the *UCL* and *LCL*.)

RF CL 30a iron

key characteristic	Specification	
	Aim	**Control Limits**
% carbon (CL 25 iron)	3.49	3.44 - 3.54
% carbon (CL 20 iron)	3.90	3.80 - 4.80
% carbon (CL 30a iron)	3.25	3.20 - 3.30
% carbon (CL 35 iron)	3.15	3.00 - 3.10

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Let's look at the aim and *control limits* of CL 30a iron to see what they mean. The measurements have to do with the amount of carbon and other ingredients in the mix.

key characteristic	**Specification**	
	Aim	**Control Limits**
% carbon (CL 30a iron)	3.25	3.20 - 3.30

The aim point is 3.25% iron is 3.25%

The best amount of carbon in CL 30a

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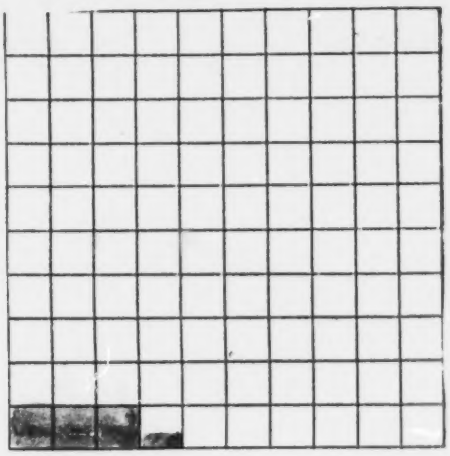
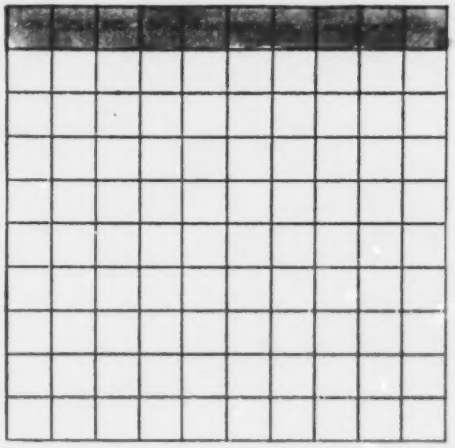
In the square below, 3.25% is darkened.



The square has been divided into 100 equal small squares. Three small squares along with a fourth of another square is equal to 3.25% That portion of the iron mix should be carbon.

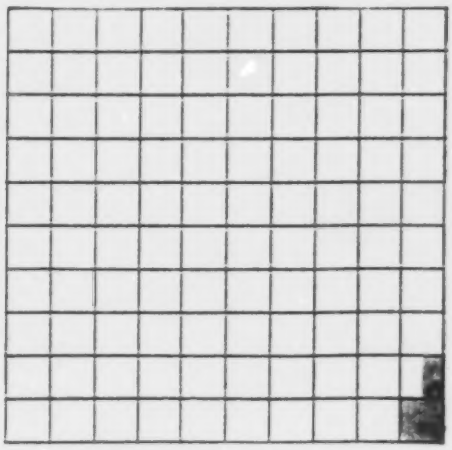
Obviously, very small amounts of carbon make a big difference.

In the square below, 10.00% is darkened.



The square has been divided into 100 equal small squares. 10 of the small squares is equal to 10.00%

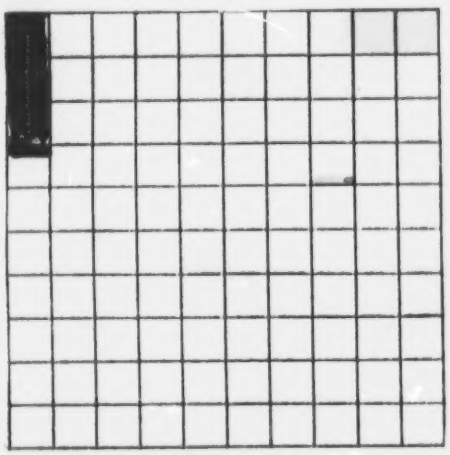
In the square below, what percentage is darkened?



Of the 100 equal small squares, 1 1/2 squares or 1.5% has been darkened.

Most of the key characteristic specifications are for very small amounts. Here are the aim point percentages, in color, for CL 30a iron:

	Aim	color
% carbon	3.25	blue
% silicon	2.15	yellow
% manganese	.55	pink
% chromium	.08	green



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	Aim
% carbon	3.25

If the Quick Lab shows that the amount of carbon is 2.25%, you need to know how far off you are from the aim point.

Subtract like this:

$$\begin{array}{r} 3.25 \\ -\ 2.25 \\ \hline 1.00 \end{array}$$

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You can add and subtract SPC measurements, as long as you line up the decimal points, like this:

```
  3.5          6.4
+ 3.1        - 3.0
  6.6          3.4
```

What is the answer to these problems?

```
  3.5
+ 3.5
```

Add the two fives, carry the one, and add 3+3+1 to get 7.0

```
  3.5
+ 3.5
  7.0
```

```
  6.4
- .5
```

Borrow one from the six, subtract 5 from 14 to get 9. Then subtract 0 from 5 to get 5.

```
  6.4
- .5
  5.9
```

You need to be able to add and subtract decimals to use SPC control charts.

The next few pages will review SPC words we've been using, and give you practice in adding and subtracting decimal numbers.

Use the answer sheet for writing down your answers. DO NOT WRITE IN THIS BOOK.

What fits best in the blank below?

a.) (UCL) Upper Control Limit
b.) key element
c.) random sample

A wrong amount of any ___ _____ gives you a defect. For instance, too much silicon in CL 30a makes brittle iron.

Turn the page for the correct answer.

a. This is not the right answer.

The Upper Control Limit (UCL)shows how high a measurement can be and still be OK. For instance, the UCL for carbon in CL 30a iron is 3.30

b. This is the correct answer.

A wrong amount of any key element gives you a defect. For instance, too much silicon in CL 30a makes brittle iron.

c. This is not the best answer.

A random sample is taken and put on the control chart. But the sample is of a key element, such as silicon, carbon, and other elements.

What fits best in the blank below?

a.) (UCL) Upper Control Limit
b.) key element
c.) random sample

SPC charts keep track of each __ _____ in the manufacturing process.

Turn the page for the correct answer.

a. This is not the right answer.

The Upper Control Limit (UCL) shows how high a measurement can be and still be OK. For instance, the UCL for carbon in CL 30a iron is 3.30

b. This is the correct answer.

SPC charts keep track of each key element in the manufacturing process.

c. This is not the best answer.

An aim point is the measurement you want to achieve. But what you are measuring is the amount of a key element.

What fits best in the blank below?

a.) specification
b.) estimation
c.) sample

The lab's _____ often sets a maximum for a key characteristic. You can't have more than .1% of moisture in new sand, for instance.

Turn the page for the correct answer.

a. This is the correct answer.

The lab's specification often sets a maximum for a key characteristic. You can't have more than .1% of moisture in new sand, for instance.

b. This is not the right answer.

An estimation is a guess or an approximation. A specification, on the other hand, is the number set by the lab as the goal.

c. This is not the right answer.

A sample is a part of the work that is measured and put on the control chart. But the specification is the number set by the lab as the goal.

Which of the following words fits best in the blank below?

a.) specification
b.) estimation
c.) sample

Other times, the _____ will be an exact number, or *aim* point. You should try to get exactly 3.25% carbon in CL 30a iron.

Turn the page for the correct answer.

a. This is the correct answer.

Other times, the specification will be an exact number, or aim point. You should try to get exactly 3.25% carbon in CL 30a iron.

b. This is not the right answer.

An estimation is a guess or an approximation. A specification, on the other hand, is the number set by the lab.

c. This is not the right answer.

A sample is a part of the work that is measured and put on the control chart. But the *specification* is the number set by the lab as the goal.

What fits best in the blank below?

a.) control chart
b.) key element
c.) random sample

The right amount for each ___ _____ is figured out by the lab.

Turn the page for the correct answer.

a. This is not the best answer.

A control chart is a graph which shows you how well your job is running.

b. This is the correct answer.

The right amount for each key element is figured out by the lab.

c. This is not the best answer.

A random sample is taken and put on the control chart. But the sample is of a key element, such as silicon, carbon, and other elements.

What fits best in the blank below?

a.) statistical process control (SPC) and non-statistical process control (N-SPC)
b.) lost foam process (EPS) and Evaporative Polystyrene System (EPS)
c.) upper control limits (UCL) and lower control limits (LCL)

You might notice that the aim point, 3.25%, is right in the middle of the _____ _____ _____ ___ and _____ _____ _____ ___.

Turn the page for the correct answer.

a. This is not the right answer.

Statistical process control(SPC) is a way of using number facts to keep track of quality.

The upper and lower control limits, on the other hand, are found on SPC charts. If sample measurements fall within the upper and lower control limits, things are going OK.

b. This is not the right answer.

The lost foam process is another name for the Evaporative Polystyrene System, or EPS.

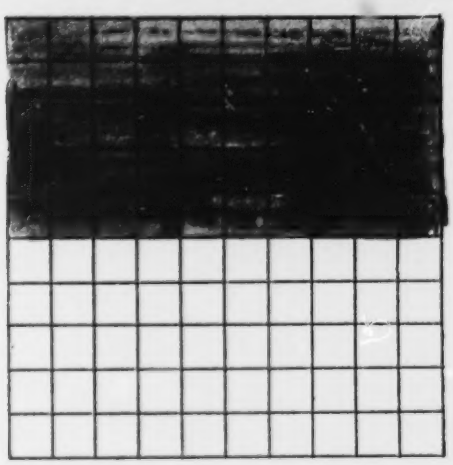
The upper and lower control limits, on the other hand, are found on SPC charts. If sample measurements fall within the upper and lower control limits, things are going OK.

c. This is the correct answer.

You might notice that the aim point, 3.25%, is right in the middle of the upper control limits UCL) and lower control limits (LCL).

What percentage of the large square is darkened?

a. 50 of the hundred small squares, or 50%
b. 3 of the hundred small squares, or 3.0%
c. 1 and-a-half of the hundred small squares, or 1.5%



Turn the page for the correct answer.

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a. This is the correct answer.

Fifty of the hundred small squares, or 50% are darkened.

b. This is not the right answer.

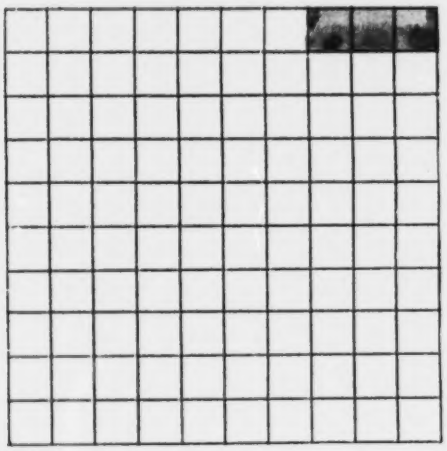
Count the squares to get the right answer: 50/100

c. This is not the right answer.

Count the squares to get the right answer: 50/100

What percentage of the large square is darkened?

a. Fifty of the hundred small squares, or 50%
b. Three of the hundred small squares, or 3.0%
c. One and-a-half of the hundred small squares, or 1.5%



Turn the page for the correct answer.

a. This is not the right answer.

Count the squares to get the right answer: 3/100

b. This is the correct answer.

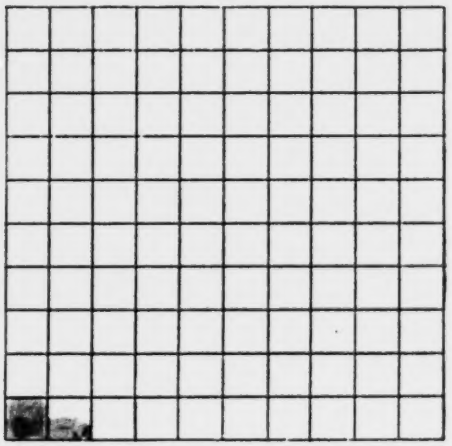
Three of the hundred small squares, or 3.0% are darkened.

c. This is not the right answer.

Count the squares to get the right answer: 3/100

What percentage of the large square is darkened?

a. Fifty of the hundred small squares, or 50%
b. Three of the hundred small squares, or 3.0%
c. One and-a-half of the hundred small squares, or 1.5%



Turn the page for the correct answer.

a. This is not the right answer.

Count the squares to get the right answer: 1 1/2/100

b. This is not the right answer.

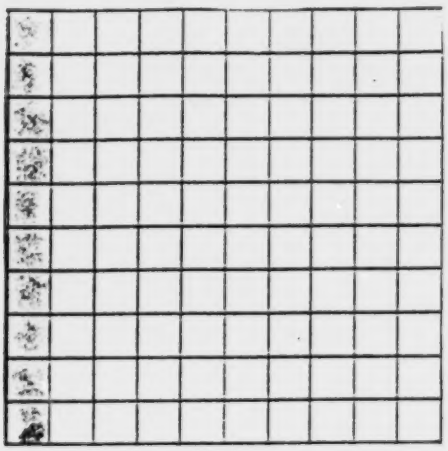
Count the squares to get the right answer: 1 1/2/100

c. This is the correct answer.

One-and-a-half of the hundred small squares, or 1.50% are darkened.

What percentage of the large square is darkened?

a.) Ten of the hundred small squares, or 10%
b.) Three of the hundred small squares, or 3.0%
c.) One-and-a-half of the hundred small squares, or 1.5%



Turn the page for the correct answer.

a. This is the correct answer.

Ten of the hundred small squares, or 10% are darkened.

b. This is not the right answer.

Count the squares to get the right answer: 10/100

c. This is not the right answer.

Count the squares to get the right answer: 10/100

What is the correct answer?

$$\begin{array}{r} 1.25\% \\ +\ \underline{1.01\%} \end{array}$$

a.) 2.80%
b.) 2.26%
c.) 22.6%

Turn the page for the correct answer.

a. This is not the right answer.

b. This is the correct answer.

$$\begin{array}{r} 1.25\% \\ +1.01\% \\ \hline 2.26\% \end{array}$$

c. This is not the right answer.

What is the correct answer?

$$\begin{array}{r} 1.90 \\ +\ \underline{1.20} \end{array}$$

a.) 2.11
b.) 3.11
c.) 3.10

Turn the page for the correct answer.

a. This is not the right answer.

b. This is the correct answer.

$$\begin{array}{r} 1.90 \\ +\ \underline{1.20} \\ 3.11 \end{array}$$

c. This is not the right answer.

What is the correct answer?

$$\begin{array}{r} 3.25 \\ -\ \underline{3.00} \end{array}$$

a.) .25
b.) 6.25
c.) 25.00

Turn the page for the correct answer.

a. This is the correct answer.

$$\begin{array}{r} 3.25 \\ -\ 3.00 \\ \hline .25 \end{array}$$

b. This is not the right answer.

c. This is not the right answer.

What is the correct answer?

$$\begin{array}{r} 3.50 \\ -\ \underline{2.19} \end{array}$$

a.) 1.31
b.) 1.41
c.) 0.131

Turn the page for the correct answer.

a. This is the correct answer.

$$\begin{array}{r} 3.50 \\ -\ \underline{2.19} \\ 1.31 \end{array}$$

b. This is not the right answer.

c. This is not the right answer.

You have finished the review questions on terms and math for the first part of the lesson. Now you'll learn about more terms and math used in Quality Control at Bodine-Robinson and Robinson Foundry.

Each time an SPC measurement is taken for a Key Characteristic, you get some idea of how close you are to the lab's specification. If you write down several of the measurements, you can *average* them.

Here's how you figure an *average*:

The amount of silicon measures at 7.09, then at 7.04, and finally at 6.93.

Add up the measurements:

```
 7.19
 7.24
+6.93
------
21.36
```

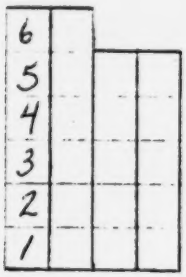
Divide by 3, since there are three measurements you added together:

```
   7.12
3/21.36
   21
   ---
    0 3
      3
      ---
      06
       6
       ---
       0
```

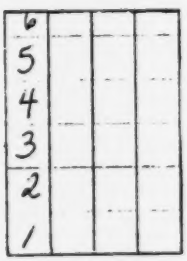
The *average* amount of silicon that shift was 7.12.

An average,then, evens out the high and low measurements, like this:

Two are six feet tall,
two are five feet tall.



All four are now five-and-a-half feet tall.



Here's another example of how to figure an average. (By the way, the silicon measurements we are averaging are those taken in the holding furnace when pouring Ford Manifolds. The aim point is 7.25.)

```
  7.00
  7.34
+ 7.38
 21.72


  7.24
3/21.72
```

Why, in this example do we divide by 4?

$$\begin{array}{r} 7.00 \\ 7.40 \\ 6.93 \\ +\ 7.25 \\ \hline 28.58 \end{array}$$

$$\begin{array}{r} 7.15 \\ \hline 4/28.58 \end{array}$$

If you have four measurements, you have to divide by four.

(You always divide by the *number* of measurements.)

The next few pages will give you practice in adding and subtracting decimal numbers.

Use the answer sheet for writing down your answers. DO NOT WRITE IN THIS BOOK.

On SPC charts you will see an $\bar{X}$. That means average, and is pronounced 'X-bar'.

What is the correct answer?

$$\begin{array}{r} 4 \\ 4 \\ +7 \\ \hline 15 \end{array} \qquad 3\overline{)15}\ 5$$

a. $\bar{X} = 15$

b. $\bar{X} = 5$

c. $\bar{X} = 3$

Turn the page for the correct answer.

a. This is not the right answer.

Fifteen is the *sum* of the sample measurements.

b. This is the correct answer.

$$\begin{array}{r} 4 \\ 4 \\ +7 \\ \hline 15 \end{array}$$

$$3\overline{)15}^{\,5}$$

Average (X) = $\dfrac{\text{sum of samples}}{\text{number of samples}}$

c. This is not the right answer.

Three is the *number* of sample measurements.

What is the correct answer?

$$\begin{array}{r} 1 \\ 4 \\ +7 \\ \hline \end{array}$$

$3/\overline{\quad}$

a. $\bar{X} = 12$

b. $\bar{X} = 5$

c. $\bar{X} = 4$

Turn the page for the correct answer.

a. This is not the correct answer.

b. This is not the correct answer.

c. This is the correct answer.

$$\begin{array}{r} 1 \\ 4 \\ +7 \\ \hline 12 \end{array}$$

$$3/\overline{12}^{\,4}$$

Average (X) = $\frac{\text{sum of samples}}{\text{number of samples}}$

What is the correct answer?

$$\begin{array}{r} 3.25 \\ \underline{3.23} \end{array}$$

$/ \overline{\quad}$

a. $\overline{X} = 3.24$

b. $\overline{X} = 4.24$

c. $\overline{X} = 6.46$

Turn the page for the correct answer.

a. This is the correct answer.

3.25
3.23
6.48

3.24
2/6.48

Average (X) = $\frac{\text{sum of samples}}{\text{number of samples}}$

b. This is not the correct answer.

c. This is not the correct answer.

What is the correct answer?

$$\begin{array}{r} 7.21 \\ 7.44 \\ \underline{+7.27} \\ \\ / \quad \overline{} \end{array}$$

a. $\overline{X} = 21.92$

b. $\overline{X} = 10.96$

c. $\overline{X} = 7.31$

Turn the page for the correct answer.

a. This is not the correct answer.

b. This is not the correct answer.

c. This is the correct answer.

$$\begin{array}{r} 7.21 \\ 7.44 \\ +7.27 \\ \hline 21.92 \end{array}$$

$$3 \overline{)21.92} \quad 7.31$$

Average (X) = $\frac{\text{sum of samples}}{\text{number of samples}}$

Another important SPC term is *range*, or R. Can you figure out the range of the second group of numbers by studying the example on the left?

Problem 1: What is the range of the three measurements?

Measurements
7.21
7.44
7.27

$$\begin{array}{r} 7.44 \\ -7.21 \\ \hline .23 \end{array}$$

R = .23

Problem 2: What is the range of the three measurements?

Measurements
7.01
7.04
6.93

R = ?

Measurements	Arithmetic to figure R
7.01	7.04
7.04	-6.93
6.93	.11

R = .11

Just subtract the smallest measurement from the biggest measurement.

The next few pages will give you practice in figuring ranges.

Use the answer sheet for writing down your answers. DO NOT WRITE IN THIS BOOK.

What is R?

7.74
7.28
7.20

a. R = .46
b. R = .54
c. R = 7.41

Turn the page for the correct answer.

a. This is not the right answer.

b. This is the correct answer.

Sample measurements	Correct arithmetic
7.74	7.74
7.28	-7.20
7.20	.54 = **R**

Range (R) = Largest measurement minus smallest measurement

c. This is not the right answer.

What is R?

7.44
7.46
7.48

a. R = .02
b. R = .04
c. R = .06

Turn the page for the correct answer.

a. This is not the right answer.

b. This is the correct answer.

Sample measurements	Correct arithmetic
7.44	7.48
7.46	-7.44
7.48	.04 = **R**

Range (R) = Largest measurement minus smallest measurement

c. This is not the right answer.

What is R?

7.44
7.44
7.41

a. R = 7.43
b. R = .03
c. R = 1.29

Turn the page for the correct answer.

a. This is not the right answer.

b. This is the correct answer.

Sample measurements	Correct arithmetic
7.44	7.44
7.44	-7.41
7.41	.03 = **R**

Range (R) = Largest measurement minus smallest measurement

c. This is not the right answer.

You have finished the review questions on terms and math for the lesson. The next few pages explain further how the average ($\bar{X}$) and Range (R) give useful quality control information.

Below, the *average* column on the right shows us how close we are to the aim point after smoothing out the highs and lows of individual measurements.

Measurements	**Average $\bar{}$ (X)**
7.01, 6.82, 7.22	7.02
7.00, 7.08, 6.93	7.00
7.21, 7.44, 7.27	7.31

Another way of looking at it is this: if the first three furnaces (measuring 7.01, 6.82, 7.22) could be mixed together, the whole big batch would measure 7.02.

(Remember, this example is of the percentage of silicon in the holding furnace when pouring Ford Manifolds, and the aim point is 7.25.)

What would you expect the missing numbers to be, approximately?

Measurements	**Average $\bar{X}$**
7.01, 6.82, 7.22	7.02
7.00, 7.08, 6.93	7.00
7.21, 7.44, 7.27	7.31
___, ____, ____	7.04

Did you expect one of the missing numbers to be as high as 12.05, or as low as 2.00?

Measurements	**Average $\bar{X}$**	**Range (R)**
7.01, 6.84, 7.22	7.02	.38
7.00, 7.08, 6.95	7.02	.13
7.02, 2.00, 12.05	7.02	10.05

Of course, a measurement of either 2.00 or 12.05 (for silicon in the holding furnace when pouring Ford manifolds) would be very unusual.

The point is, though, the average ($\bar{X}$) smooths out the differences, while the range (R) shows us how far apart the measurements are.

Measurements	**Average ($\bar{X}$)**	**Range (R)**
7.01, 6.84, 7.22	7.02	.38
7.00, 7.08, 6.95	7.02	.13
7.02, 2.00, 12.05	7.02	10.05

Without the range, you can't predict accurately. Look at the ways that 3 numbers can <u>average the same</u> but have <u>different ranges</u>.

Measurements	Average $\bar{X}$	Range (R)
7.01, 6.84, 7.22	7.02	.38
7.00, 7.08, 6.95	7.02	.13
7.02, 2.00, 12.05	7.02	10.05

In this lesson you have learned about the terms and math used in SPC.

Next you will do a short quiz.

Use the answer sheet for writing down your answers. DO NOT WRITE IN THIS BOOK.

Quiz

Answer true or false for each question.

1. The lab's specification for a key element may be a maximum or a minimum, but never an aim point.

a.) true
b.) false

2. The Control Limits for CL 30a iron are 3.20-3.30. That means that a measurement of 3.24 is within the limits.

a.) true
b.) false

3. A large square is divided into 100 equal smaller squares. Three and a half small squares are equal to 3.5% of the large square.

a.) true
b.) false

4.
$$\begin{array}{r} 3.25 \\ +3.25 \\ \hline 6.50 \end{array}$$

a.) true
b.) false

5.
$$\begin{array}{r} 7.21 \\ -7.09 \\ \hline .13 \end{array}$$

6. $\bar{X}$ on an SPC chart means the average, or mean.

a.) true
b.) false

7. To figure an average ($\bar{X}$), add up the items and divide by the number of items added.

a.) true

b.) false

8. To figure a range, add the top two numbers.

a.) true
b.) false

9. This average is figured correctly.

measurements	arithmetic	
7.02, 6.82, 7.22	7.02 6.82 +7.22 21.06	3/21.06

a.) true
b.) false

10. This range is figured correctly.

measurements	arithmetic
7.01, 6.82, 7.22	7.22 -6.82 .40

a.) true
b.) false

Turn the page for the correct answers.

Answers to Quiz

Answer true or false for each question.

1. The lab's specification for a key element may be a maximum or a minimum, but never an aim point.

false

2. The Control Limits for CL 30a iron are 3.20-3.30. That means that a measurement of 3.24 is within the limits.

true

3. A large square is divided into 100 equal smaller squares. Three and a half small squares are equal to 3.5% of the large square.

true.

4.
```
  3.25
+3.25
 6.50
```

true

5.
```
  7.21
-7.09
  .13
```

false

6. $\bar{X}$ on an SPC chart means the average, or mean.

true

7. To figure an average ($\bar{X}$), add up the items and divide by the number of items added.

true

8. To figure a range, add the top two numbers.

false

9. This average is figured correctly.

measurements	arithmetic
7.02, 6.82, 7.22	7.027.02 6.82 3/21.06

+7.22

21.06

true

10. This range is figured correctly.

measurements	arithmetic
7.01, 6.82, 7.22	7.22
	-6.82
	.40

true

ANSWER SHEET

For each question, circle your answer, then check (on the next page in the lesson book) whether it is right.

Page 16

a.)
b.)
c.)

Page 18

a.)
b.)
c.)

Page 20

a.)
b.)
c.)

Page 22

a.)
b.)
c.)

Page 24

a.)
b.)
c.)

Page 26

a.)
b.)
c.)

Page 28

a.)
b.)
c.)

Page 30

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Page 32

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Page 34

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Page 36

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Page 42

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c.)

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b.)
c.)

Page 60

a.)
b.)
c.)

Page 62

a.)
b.)
c.)

Page 64

a.)
b.)
c.)

Quiz

1.

a.) true
b.) false

2.

a.) true
b.) false

3.

a.) true
b.) false

4.

a.) true
b.) false

5.

a.) true
b.) false

6.

a.) true
b.) false

7.

a.) true
b.) false

8.

a.) true
b.) false

9.

a.) true
b.) false

10.

a.) true
b.) false